Schafer

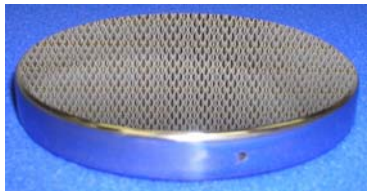
Lightweight Optical Systems (LWOS)

Superior Technology with a System Level Point-of-View©

Qualification of Materials for Low Cost Kill Vehicles

Phase I SBIR for Adam Aberle

Dimensionally Stable SLMS™



10 kHz 1st Fundamental SiC-SLMS™

C/SiC

Dr. Bill Goodman
LWOS Business Lead
Schafer Corporation
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Albuquerque, NM 87106

505.338.2865

wgoodman@schaferalb.com

Mirror Technology Days
August 2005

Schafer

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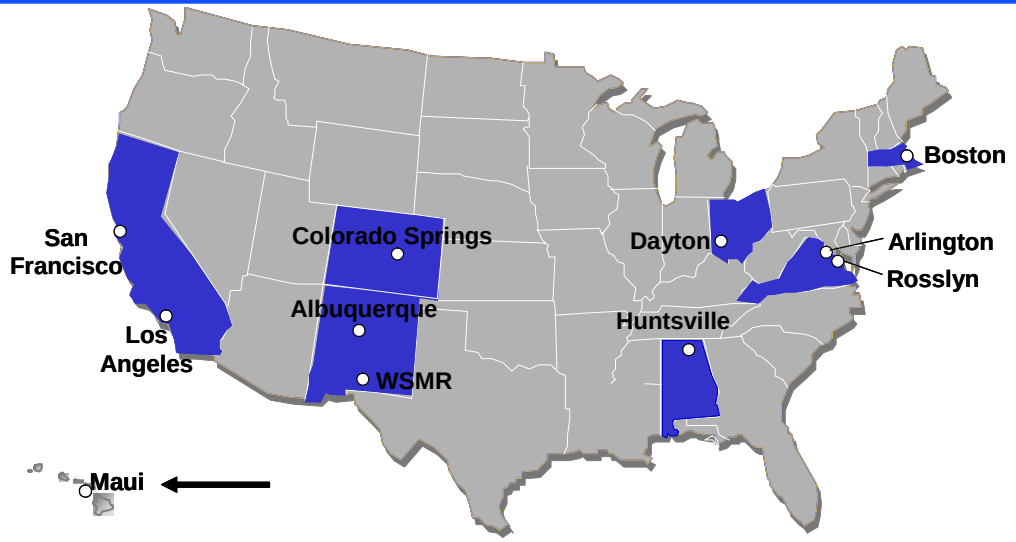
Company Information



Space and Directed Energy Division, Albuquerque Operation
Lightweight Optical Systems

- Lightweight Optical Systems (LWOS) & Laboratory Based in Albuquerque, NM
- Employees: 380
- 2004 Sales of $78M, 2005 Sales Projected at $90M
- Capabilities - **Lightweight Optical Systems, Optical Coatings, EO & IR Sensors, Advanced Projectiles & Seekers, Lasers and Other DE, Laser Radar**

Schafer Corporation Has A Broad Spectrum of Capabilities That Can Address The Needs of LCKV and Other Programs

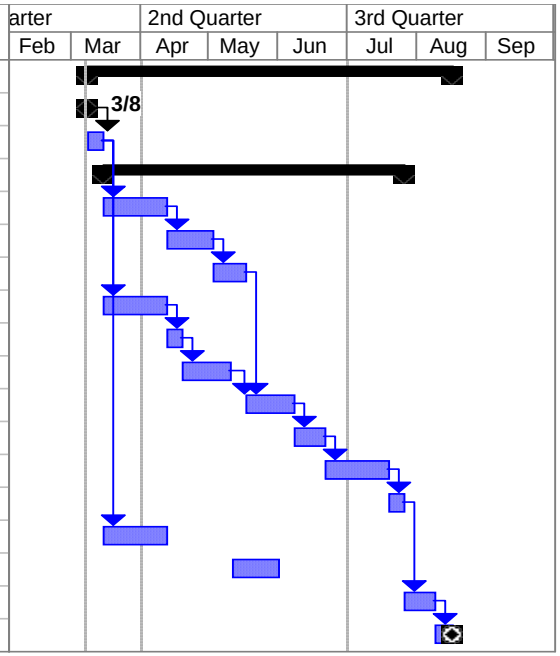
Contract Information

- Contract Executed March 4, 2005
- Contracting Agency
  - ⇒ COR is U.S Army Space and Missile Defense Technical Center, Mr. Adam Aberle
  - ⇒ Missile Defense Agency CTV, Mr. Dale McNabb
- Topic MDA04-112, "Ballistic Missile Innovative Electro-Optic Products" sponsored by MDA/AS
- Principal Investigator for Schafer is Dr. Bill Goodman
  - ⇒ wgoodman@schaferalb.com, 505-338-2865 Direct, 505-400-8169 Cell
- Technical Monitor for SMDC is Mr. Adam Aberle
  - ⇒ US Army Space and Missile Defense Technical Center
    Interceptors Division
    Engineer, LADAR Technology
    SMDC-RD-TC-MT-KC
    PO BOX 1500
    Huntsville, AL 35807-3801
    Phone: 256-955-5478
    Fax: 256-955-3641/3508
    email: adam.aberle@smdc.army.mil

Schedule/Deliverables

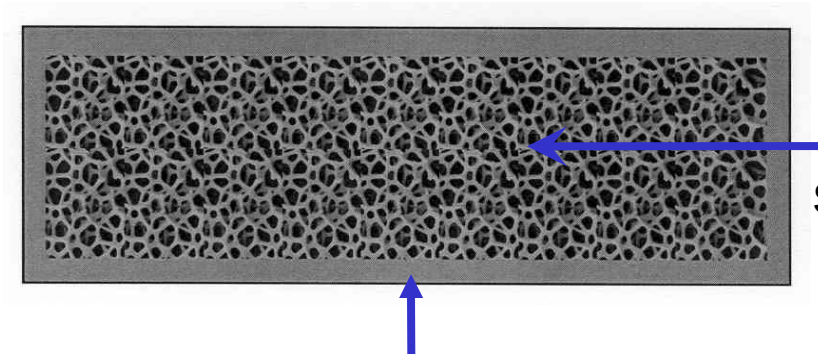
- 3-inch diameter SLMS™ and SiC-SLMS™ plano mirrors
  - ⇒ VIS/IR Performance, Figure of $\lambda_{HeNe}/10$ PV , Surface roughness of 10 Å RMS
  - ⇒ Solid Models of Mass/Frequency, Laser Vibrometer & Mass Measurements
- Schafer designed coating
- Mirror Flash X-Ray testing

ID	Task Name	Duration	Start	Finish
1	**Materials for LCKV**	**115 days**	**Tue 3/8/05**	**Mon 8/15/05**
2	Kick-Off Briefing	0 days	Tue 3/8/05	Tue 3/8/05
3	Requirements Definition with Raytheon	1 wk	Tue 3/8/05	Mon 3/14/05
4	**Task 1: Hardware Production**	**95 days**	**Tue 3/15/05**	**Mon 7/25/05**
5	Produce SLMS & SiC-SLMS Substrate Cores	4 wks	Tue 3/15/05	Mon 4/11/05
6	Precision Machine Substrate Cores	3 wks	Tue 4/12/05	Mon 5/2/05
7	Deposit Substrate Facesheets	2 wks	Tue 5/3/05	Mon 5/16/05
8	Produce C/SiC Greenbodies	4 wks	Tue 3/15/05	Mon 4/11/05
9	Infiltrate C/SiC	1 wk	Tue 4/12/05	Mon 4/18/05
10	Precison Grind C/SiC	3 wks	Tue 4/19/05	Mon 5/9/05
11	Figure and Finish Substrates	3 wks	Tue 5/17/05	Mon 6/6/05
12	Inspect Mirror Figure/Finish, Vibrometry	2 wks	Tue 6/7/05	Mon 6/20/05
13	Deliver Substrates to Surface Optics for Coating	4 wks	Tue 6/21/05	Mon 7/18/05
14	Perform Metrology	1 wk	Tue 7/19/05	Mon 7/25/05
15	Task 2: Materials Properties Database	4 wks	Tue 3/15/05	Mon 4/11/05
16	Task 3: Structural Predictions	3 wks	Wed 5/11/05	Tue 5/31/05
17	Task 4: Flash X-ray tests	2 wks	Tue 7/26/05	Mon 8/8/05
18	Final Report and Deliverables	1 wk	Tue 8/9/05	Mon 8/15/05



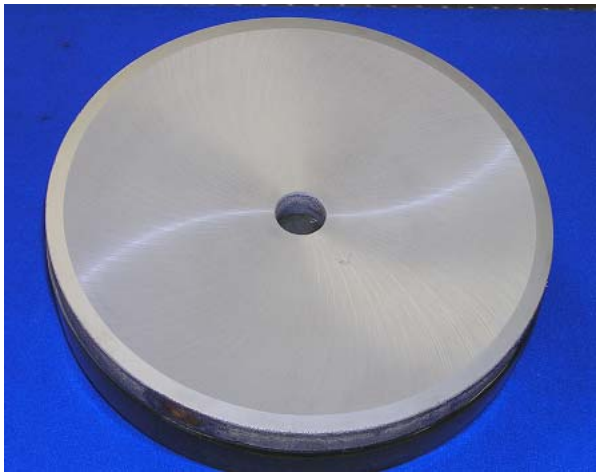
SLMS™ and SiC-SLMS™ Mirror Systems

- **Foam Core Optics with a Continuous Shell**

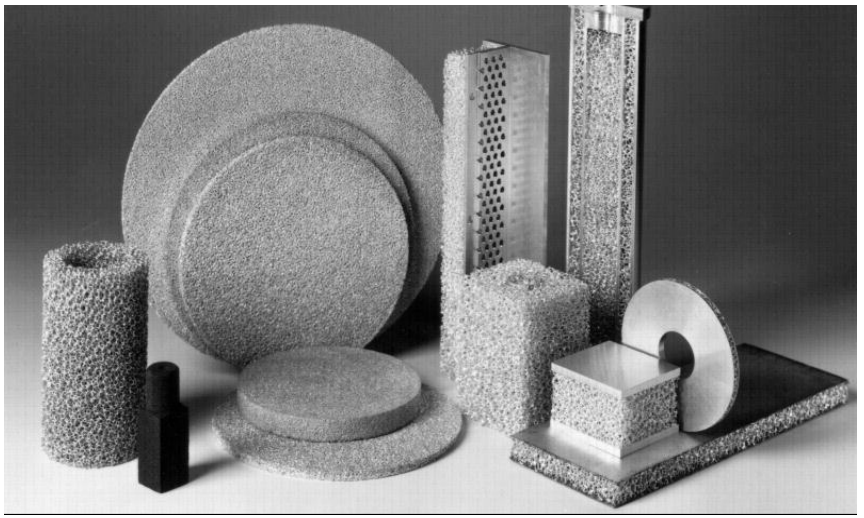


Silicon or Silicon Carbide Foam

Polycrystalline Silicon or Beta-Silicon Carbide Closeout 0.25-1.27 mm typical (0.01-0.05 inch)



- **Foam is Open-Cell, 70-95% Porosity**
- **Pore Size: 0.40 - 4.0 per mm (10-100 per inch)**
- **CNC machined to virtually any shape to ± 50 µm (0.002 inch)**



Design Flexibility with Large Manufacturing Basis

Schafer

Lightweight Optical Systems (LWOS)

Superior Technology with a System Level Point-of-View©

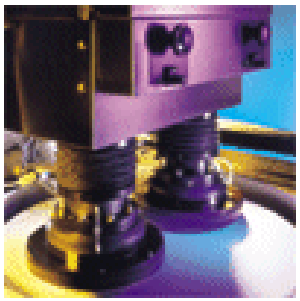
SLMS™ & SiC-SLMS™ Manufacturing

Monolithic Substrates to 65 cm diameter

Polishing: Conventional or 2-Step Deterministic Polishing

Metrology: Interferometry, Computer Generated Hologram

Multiple Vendors Qualified



Multiple Coaters Qualified

SiC clad SiC Foam

Silicon Encapsulated

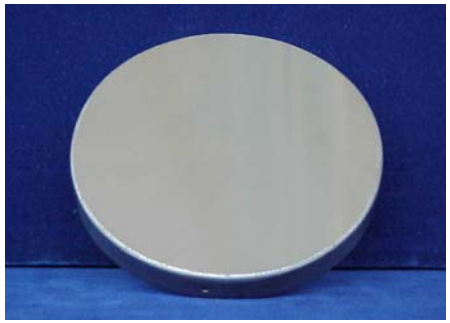
Cost Less Than Beryllium – Polishes Like Glass – ISO9001 Processes

Can Offer CPFF or FFP Contracting

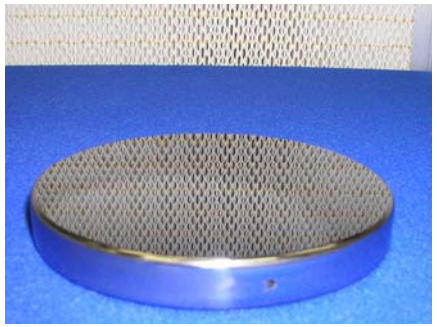
SiC-SLMS™ Fast Steering Mirrors

- **SiC-SLMS™ Steering Mirror**
- **Lightweight, High First Frequency SiC-SLMS™ substrate**

1) SiC clad SiC Foam



2) Silicon Encapsulated



3) Polished Mirror

4) Coated Mirror

- **96% Clear Aperture (4.85 inch)**
- **Figure: $\lambda/77$ rms HeNe**
- **Finish: 3.8 Å rms**
- **Radius Edge Finish: 4.7 μin**
- **Scratch/Dig better than 20/10**
- **1st Fundamental: 9.6 kHz**
- **Weight: <0.47 pound**

Laser Tested May 11, 2005 – Excellent Performance!

Material Properties

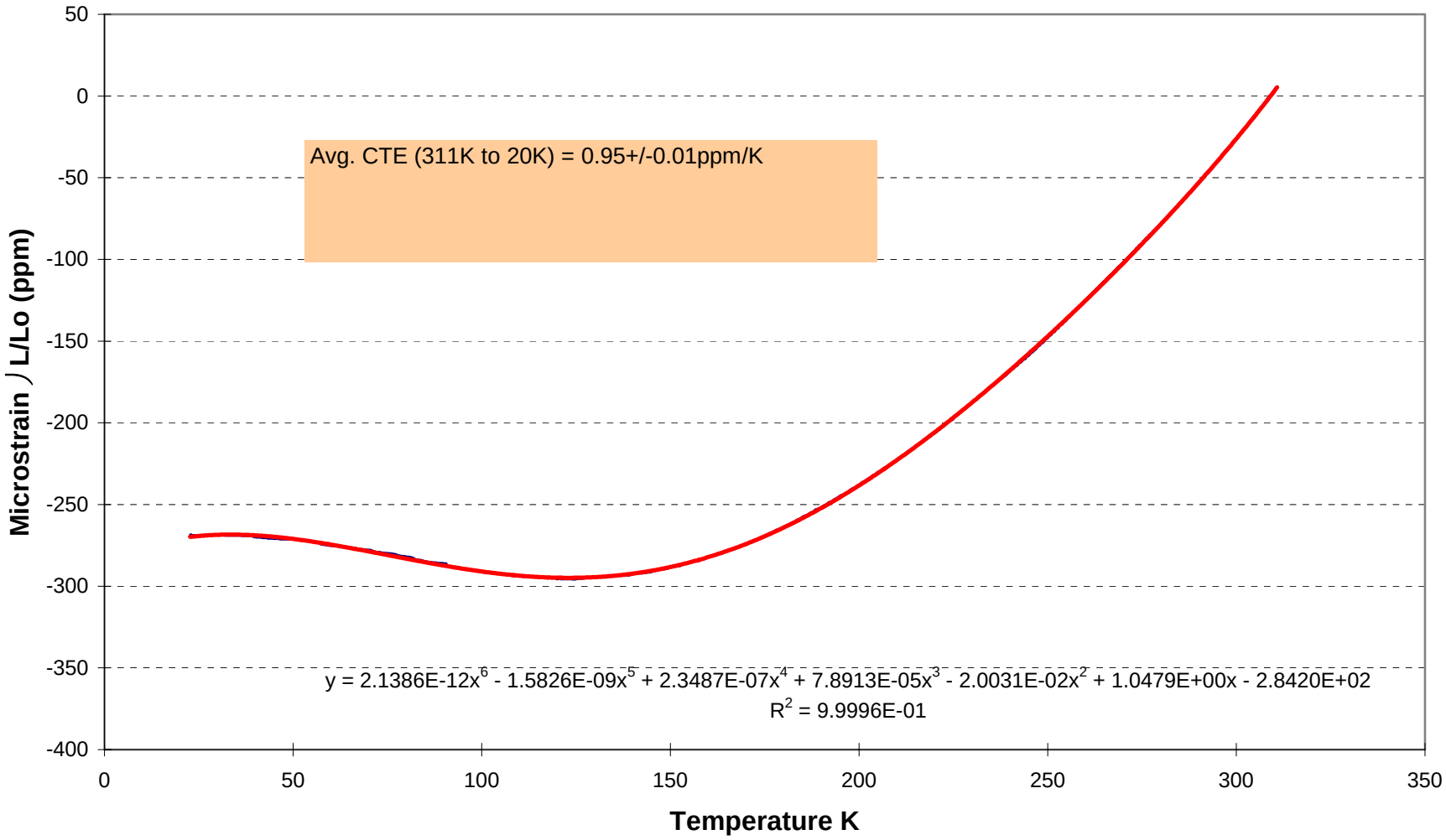
Room Temperature Property:	Density	Young's Modulus	Specific Stiffness	Tensile Strength	Specific Strength	Thermal Expansion	Thermal Conductivity	Specific Heat	Thermal Diffusivity	Steady State Distortion	Transient Distortion	Poisson's Ratio	Surface Finish
Units:	kg/m^3	GPa	$MPa\text{-}m^3/kg$	Mpa	$MPa\text{-}m^3/kg$	$10^{-6}/K$	W/m-K	j/kg-K	$10^{-6}/m^2/s$	Hm/W	$s/m^2\text{-}K$	arbitrary	nm
Preferred Value:	Small	Large	Large	Large	Large	Small	Large	Large	Large	Small	Small		Small
PRESENT SOTA													
Fused Silica	2190	73	33		0.00	0.5	1.4	750	0.85	0.36	0.59		10
ULE Fused Silica	2210	67	30		0.00	0.015	1.3	770	0.76	0.01	0.02		10
Zerodur	2530	92	36		0.00	-0.09	1.6	810	0.78	-0.06	-0.12		15
Beryllium I-70 Optical	1850	287	155	237	0.13	11.3	216	1920	60.81	0.05	0.19	0.25	15
SCHAFER TECHNOLOGIES													
Foam Silicon SLMS™ Skin	2330	130	56	120	0.05	2.5	148	750	84.69	0.02	0.03	0.24	5
Foam Beta-SiC SLMS™ Skin	3210	460	143	470	0.15	2.2	380	640	184.97	0.01	0.01	0.21	5
Web Based C/SiC	2655	249	94	150	0.06	2.5	121	800	56.97	0.02	0.04	0.24	10 to 25

SLMS™ Has Distortion Parameters Like Low Expansion Glasses With More Than 2 times the Specific Stiffness (Equates to Lower Mass)

SiC-SLMS™ Has Superior Thermal Performance Than Be With Similar Structural Properties

Schafer Has Invested IR&D Funds to Verify Key Properties

Si Foam Microstrain vs T

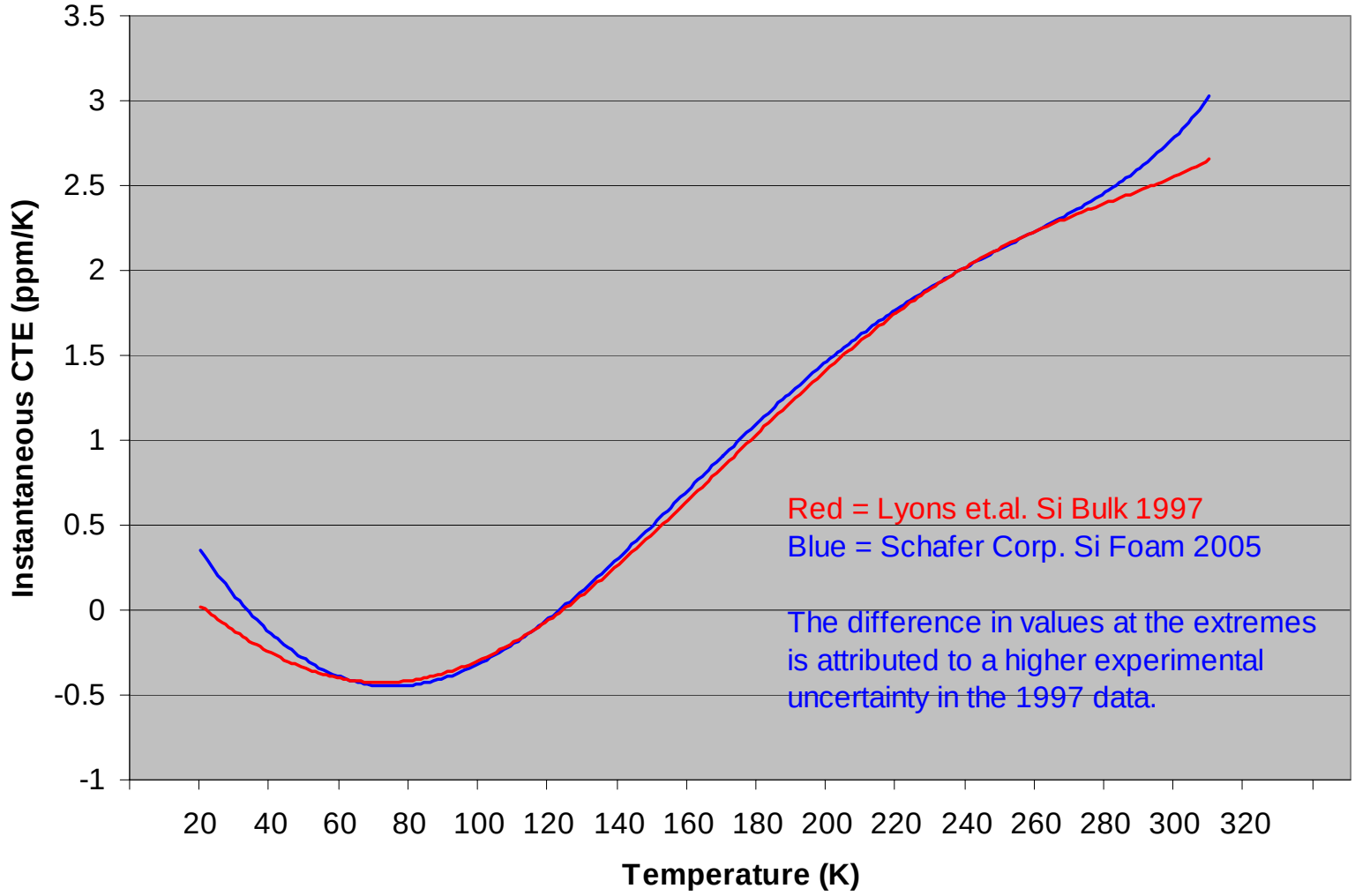


Cyclic Testing Performed by PMIC

Foam Microstrain Same As Bulk Material

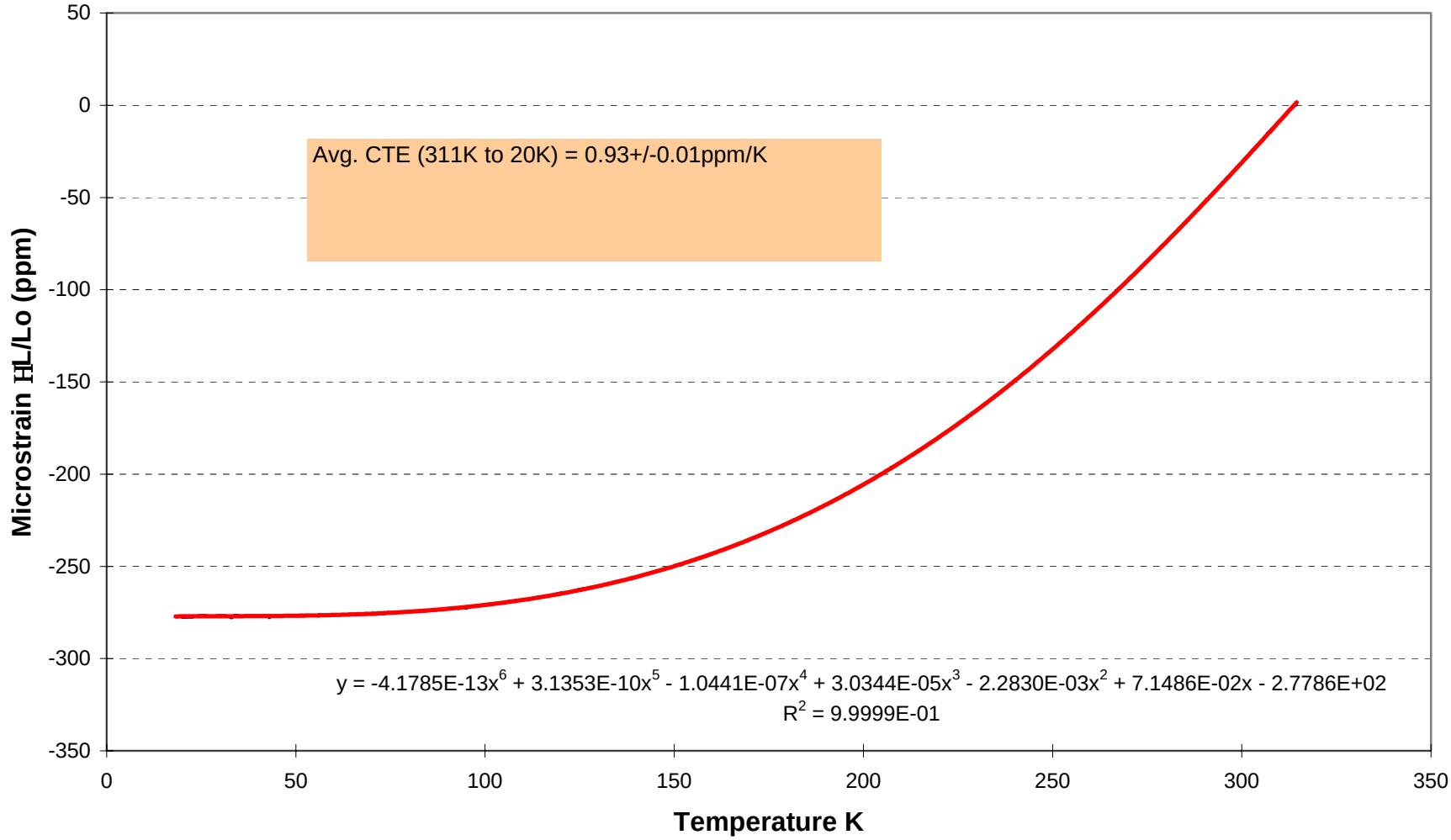
CTE of Bulk Si and Si Foam

- Near Perfect Agreement Between Bulk and Foam CTE



Foam and Bulk Material Behave The Same (2.5 ppm/K at 295 K)
Near-Zero CTE from 25-125 K – Premium for Cryo Telescopes

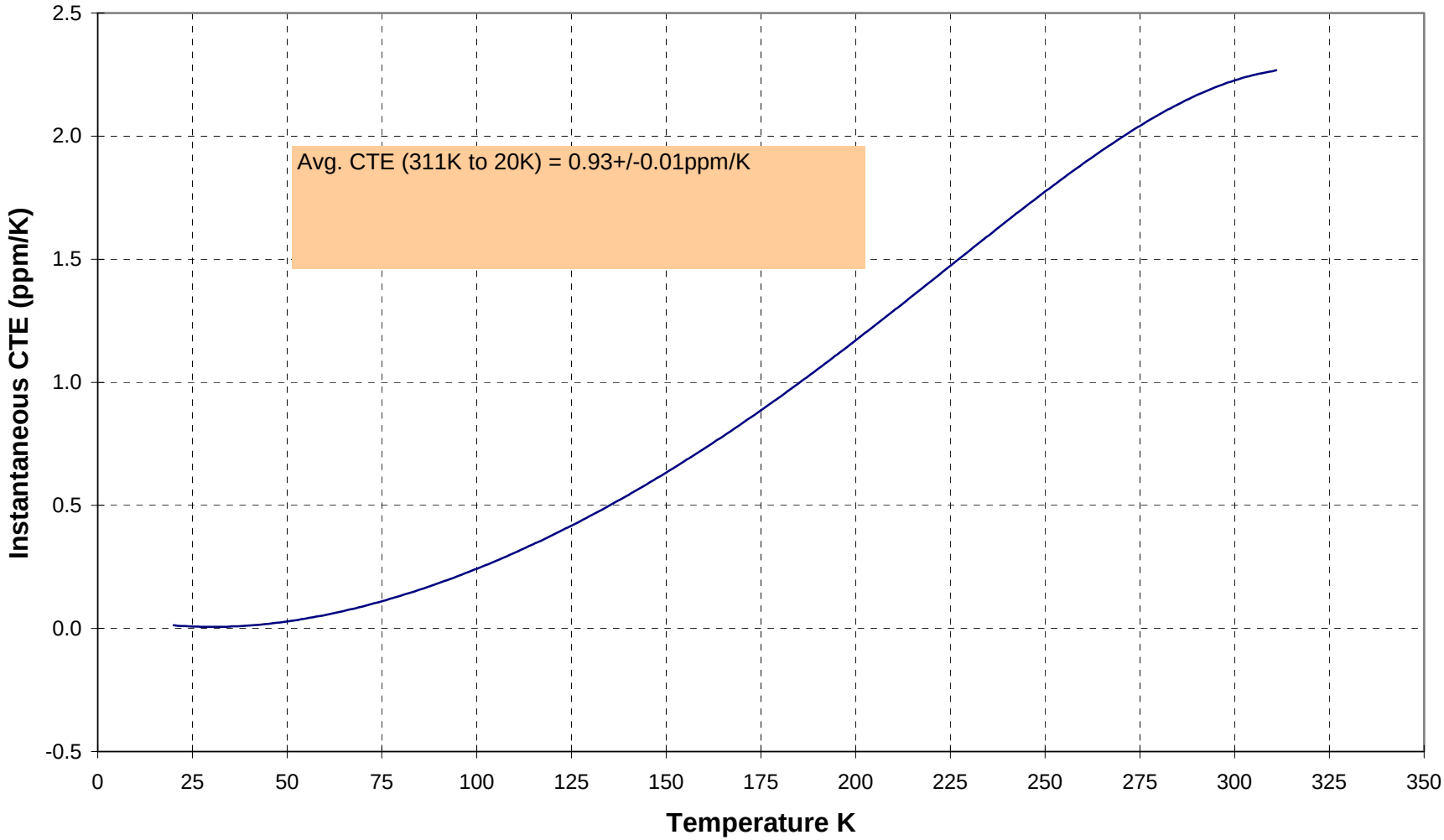
β-SiC Microstrain vs T



Cyclic Testing Performed by PMIC

Foam Microstrain Same As Bulk Material

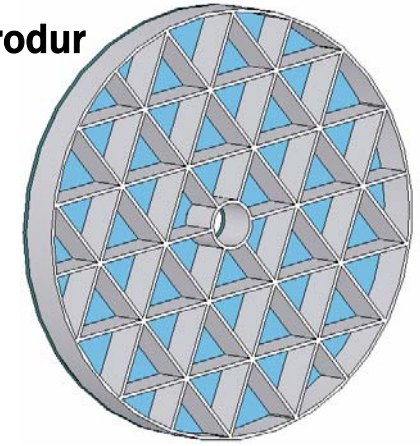
β-SiC Instantaneous CTE



Foam and Bulk Material Behave The Same (2.2 ppm/K at 295 K)
Zero CTE at 30 K – Premium for Cryo Telescopes

Structural Efficiency

Be, ULE, Zerodur



Schafer Technology

Mirror	1st Frequency (kHz)	Mass (kg)	Areal Density (kg/m^2)
ULE	1.76	0.98	16.1
Zerodur	1.93	1.12	19.4
Beryllium	3.98	0.81	13.3
SLMS	4.29	0.81	13.3
SiC-SLMS	5.24	0.81	13.3

SLMS™ and SiC-SLMS™ Are Stiffer than Be at Same Mass or Lighter at Same Stiffness

High Precision SLMS™

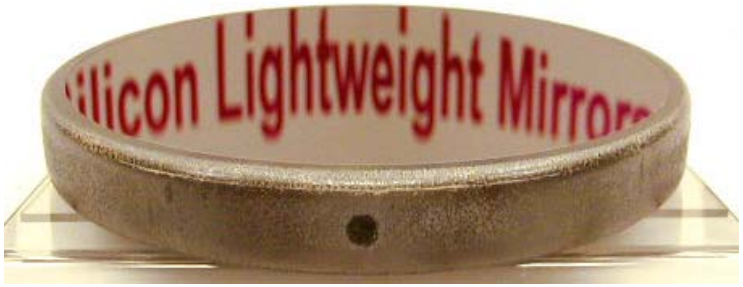


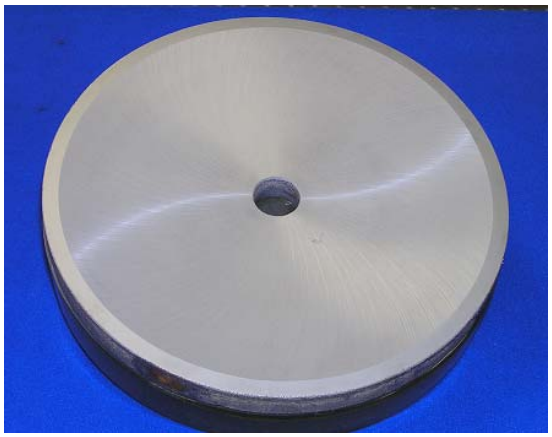
Figure of Merit	Specified Value	Results Achieved	Achievable
Areal Density, kg/m^2	<20	**9.8**	6
Surface Figure at 80% CA, waves rms @633 nm	0.02	0.021	0.005
Surface Figure at 95% CA, waves rms @633 nm	N/A	0.027	0.010
Surface Roughness, Å rms	10	**4**	1
Radius of Curvature	600 mm ± 0.5%	**598.559 ± 0.005 mm 2-σ**	
Surface Quality (Scratch/Dig)	60/40	**20/20**	10/5

SLMS™ Achieved or Exceeded ALL Specifications

Optical Quality Suitable For IR Through Extreme UV

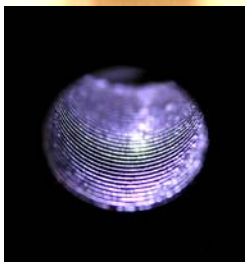
C/SiC Telescope

- SLMS™ Primary mirror, single crystal silicon secondary, and C/SiC supporting structure
- C/SiC M10 or M12 screws - high tensions of 40,000-50,000 N
- High fracture toughness



¼-80 Alignment Screw

¼-80 Threads

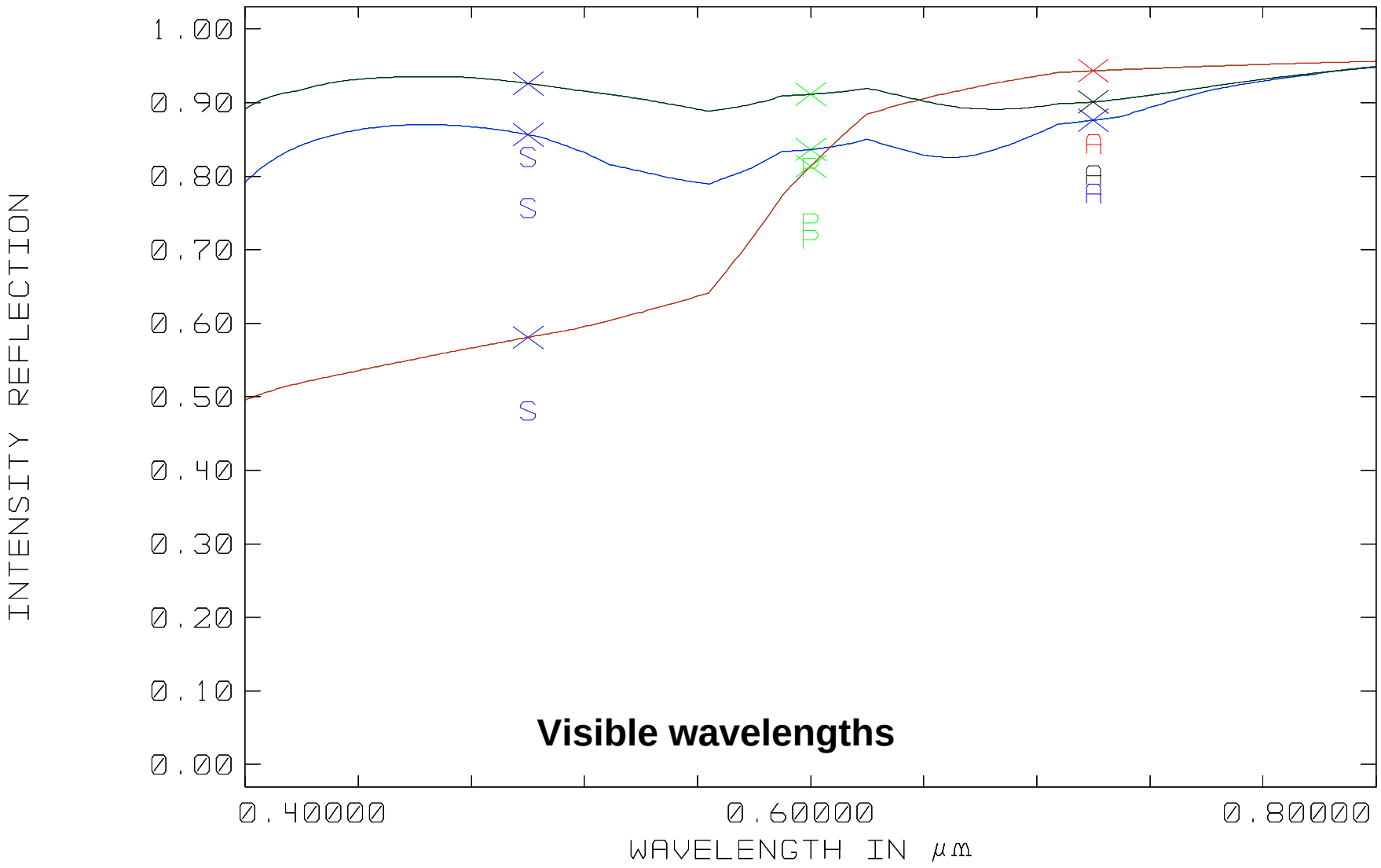


¼-20 Assembly Screw

¼-20 Threads

25.4 cm Clear Aperture with Total Telescope Mass of 6.4 kg (14 lbs)

Coating in Visible



Coating in LWIR